NAVIGATION

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A SHORT COURSE

EXPLAINING THE PRINCIPAL PROBLEMS MET WITH IN ORDINARY, EVERYDAY WORK AT SEA

BY

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To

COMMODORE E. C. BENEDICT

VETERAN YACHTSMAN

Whose yachting record of 400,000 miles has made him preëminent among deep sea yachtsmen. A royal host, who has given pleasure to so many friends; to him, by one of his frequent guests and many admirers, this book is dedicated in affectionate and grateful memory.

THE AUTHOR.

AUTHOR'S PREFACE

THE scarcity of navigators in the present national emergency is little known and very little appreciated. It has been proposed to build upward of one thousand ships in the immediate future. These would require a thousand captains and two or three thousand mates. Where are they to be found? In the various branches of the naval service there are already enlisted about 35,000 young men, a large number of whom are anxious to learn navigation. Nautical schools are very few, competent teachers are very scarce, and the facilities for acquiring a knowledge of navigation are entirely inadequate to our present needs. The present course in the navy, and even the shorter courses given in the nautical schools and colleges, are all too long to meet the exigencies of the present conditions. This is because a great deal is taught in these courses that is not absolutely essential to make a practical navigator. The all-important ques-

tion, therefore, is, What is the minimum course to fit a man to assume the duties of ensign, or second or third mate, and after having attained either of those positions, to continue his studies while at sea, and so prepare himself for advancement to the successive higher grades?

The author, as a result of many years of practical experience in practical navigation on the North Atlantic, the Mediterranean, along our North Atlantic coast, and in the West Indies, has formulated a short course in navigation which has had the unqualified approval of a number of naval officers and experienced navigators of the highest authority, who agree that the knowledge of the various methods and problems embraced in this brief treatise would qualify a man, acting as sole navigator, to take a ship to any part of the world.

In acquiring the knowledge and practical experience which come only from doing the actual work at sea, the author gratefully acknowledges himself indebted to the various eminent commanders who have extended to him the courtesies of bridge and chartroom while working with the officers during frequent trans-

atlantic and other voyages. Conspicuous among these men have been the late Captain Horatio Mackay, formerly Commodore of the Cunard Line; the late Captain Albers, formerly Commodore of the Hamburg-American Line, who steered the *Deutschland* with her engines some 500 miles after losing her rudder, and then dropped dead on the bridge just as he brought the ship safely to her destination; Captain ——— of the *Persia,* who was commodore of the famous P. and O. Line, while on a trip from India to London; and Captain Charles Polack, that past grand master in the science of navigation, who, as commander of the North German Lloyds ship *Kronprinzessin Cecilie* at the outbreak of the present war, turned his ship in mid-ocean and brought her safely into Bar Harbor on the Maine coast with her precious load of gold. The author's first acquaintance with Captain Polack was on the old *Werra* on a Mediterranean trip some seventeen years ago. His great skill as a navigator, his broad experience in and knowledge of so many other subjects, his uniform courtesy and charm of manner, have combined to place him among the

best known and most popular men on the North Atlantic.

Not to be forgotten are numerous trips to Bermuda and the West Indies with such well-known commanders as Captain Fraser, Captain Mackenzie, and others. With a thorough knowledge of the theory of navigation, the value of such a varied experience in practical work at sea cannot be overstated.

The course of study upon which we are entering, stated briefly, is as follows:

First:

Chart sailing and coast pilotage, with the use of parallel rulers and dividers.

Four-point bearings, cross bearings, danger angles, both horizontal and vertical.

How to use a pelorus on a compass for measuring the angles of such bearings.

How to take azimuths of the sun for compass error.

How to ascertain the error of the compass.

How to discriminate between variation and deviation of the compass, and how to correct them.

Second:

Dead reckoning in its various branches.

Estimating distance run by patent log, or by revolutions of the engines.

The use of traverse tables for determining the position of the ship, course, distance, etc., both by middle-latitude and by Mercator sailing.

Course and distance between two given points.

The difference between longitude and departure and how to convert either one into the other by the use of traverse tables.

Third:

To convert "observed" into "True Central Altitude" by applying the four corrections for semi-diameter, dip, parallax and refraction, or by the application of a single correction; also "index error."

To calculate the declination of the sun, at any time, from the nautical almanac.

How to apply the "hourly difference," morning or afternoon, and whether the declination is increasing or decreasing.

Fourth:

To determine latitude by a meridian observation of the sun; also by a star or planet.

Fifth:

How to determine longitude by a chronometer sight of the sun.

How to get latitude by dead reckoning.

How to compute "polar distance" from the almanac.

How to determine and apply "equation of time."

How to convert "apparent" into "mean time," and vice-versa.

How to convert arc into time, or time into arc.

How to "rate" a chronometer.

INTRODUCTION

I HAVE read Commodore Hastings' elementary work on Navigation and I cordially commend it to the student, particularly to the beginner, on account of the clearness and lucidity of its explanations of the various complex questions involved.

Commodore Hastings' long years of study and his wide and varied experience in practical deep sea work have peculiarly fitted him for instructing others in the science of navigation and I believe that in our present national emergency his book will help to fill a widespread want.

J. W. MILLER,
Commodore N. M., N. Y.,
Late Lieut. Commander, U. S. N.

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NAVIGATION

CHAPTER I

CHART SAILING

THIS is a comparatively simple branch of the science; it is, nevertheless, an exceedingly important one. Many of our younger men have had more or less experience in laying out courses and measuring distances on a chart by the use of parallel rulers and dividers.

For example: a vessel bound east on Long Island Sound takes her departure from Execution Light, and first determines how far to the north from Eaton's Neck she wishes to pass—say, two miles. On the chart place one edge of the parallel rulers on Execution Light, a little to the southward, and the other end on the position desired N. of Eaton's Neck. Then move the other leg of the rulers over the near-

est compass diagram on the chart until it touches the center of the compass rose, and the course will be read on the periphery of the rose. Now, with the dividers, measure the distance, using the "scale of miles" usually found near the margin of the chart, or the minutes of latitude always found on the margin, counting each minute for a mile.

The navigator should be able to know when he gets Eaton's Neck Light abeam, i. e., at right angles to his course, which we assume has been due E., and will wish to know how far his vessel is off shore, so that he may get a new point of departure from which to determine his next course. The simplest and most practical method of determining the position is what is known as the "four-point bearing," with which every navigator or pilot should be familiar. For the purpose of demonstrating let us say that the vessel is approaching Eaton's Neck on a course due east. The light will be on the starboard hand, or to the southward; four points, counting from the east would be southeast, or an angle of 45 degrees; and eight points would be south, or an angle of 90 degrees to the vessel's

course. The compass must be provided with some simple form of pelorus, or sight vane, with which the compass-bearing of any object may be measured at any time. Then the navigator must know his vessel so as to be able to determine as nearly as possible the exact rate of speed at which he is moving. This is done either by a taffrail, or patent log, or by counting the revolutions of the engines, or by both, one checking the other. These calculations should in turn be checked by the ship's log, in which should be recorded the exact time of passing each lighthouse or buoy, or other mark on the course. These distances being shown by the chart, the exact rate of speed may easily be computed by the navigator, who should constantly and unceasingly watch these conditions so that he may always be able to compute the speed of the vessel with the greatest accuracy. Now, as we approach Eaton's Neck, the pelorus, or sight vane, should be set on the compass at four points, or 45 degrees, which on our easterly course would be southeast. While one man holds a watch, or stands over the chronometer, the navigator stands over and sights the com-

pass, and the instant the lighthouse bears southeast, "time" is called, and the hours, minutes, and seconds carefully noted. Then the pelorus is set at south, or 90 degrees to the course, and the instant the light bears south, or abeam, the time is taken in the same way. This gives us a right-angled triangle of which the first bearing is the hypotenuse, and the other two sides must be of equal length. By knowing the rate of speed and the exact time between the two sights the length, or distance run, is easily determinable, and as the two sides of the triangle are equal, this distance run must be the same as the distance from the second sight to the lighthouse. For example: suppose the vessel's rate of speed to be twelve knots per hour, or one mile in five minutes; time of first sight with light bearing S. E. or 45 degrees, ten o'clock; time of second sight with light bearing south, or 90 degrees, twenty-five minutes past ten. As the vessel is making one mile every five minutes, during this run of twenty-five minutes she will have made five miles, which is the distance between the two sights, and which, as explained, must be the distance between the posi-

tion of the second sight and the lighthouse. This position, then, is noted on the chart and is used as a new point of departure from which to lay the next course.

Other methods for obtaining position are vertical and horizontal danger angles, cross bearings, etc. These angles are usually measured with a sextant. By measuring the vertical angle of a lighthouse, the height of which above the water level is given by the chart, the distance from the light may be computed; or by using the sextant horizontally and measuring the angle of two separate objects noted on the chart, and then drawing lines on the chart from these objects and taking the intersection of those lines as the position of the ship. These two methods, however, are more or less unsatisfactory; the first, because the height of the light is so small as compared with its distance, and the second, because it is seldom that two objects are found conveniently located for the purpose of such observations. Cross bearings are frequently used, but, as they also require two objects distinctly located on the chart, they are less convenient than the four-point method. The

student is therefore strongly recommended to make himself familiar with the practice of the latter. The others may be learned later.

CHAPTER II

MEAN AND APPARENT TIME

BEFORE proceeding to consider compass error, the student must understand the difference between mean and apparent time, in order that he may learn how to use the azimuth tables for computing the sun's true bearing at any given time.

Mean time is time as shown by a clock, and its progression is regular and even throughout the twenty-four hours. Apparent time is the time shown by the sun. It is irregular in its movement, and as this irregularity is changeable it would be impossible to make a clock or any other mechanical instrument to record it. The difference between mean and apparent time is known as the "equation of time," and is given in the nautical almanac for every day and hour in the year. To convert mean time into apparent time the equation must be applied

to the mean time, minus or plus, according to the sign given in the nautical almanac; but we must first find the local mean time. For example, in New York our clocks are run on the time of the 75th meridian, i. e., on the mean or clock time of longitude 75 degrees west. Now 75° west would be somewhere in western New Jersey. What we must have is the local mean time of our position, say in New York City. Now in 24 hours the sun passes through 360 degrees of longitude, which is at the rate of 15 degrees per hour ($24 \times 15 = 360$). Time and longitude, which are one and the same thing, begin to count at Greenwich, near London, England. We know that between English time and our own time in New York there is a difference of five hours. Thus, five hours at 15 degrees per hour equals 75 degrees west longitude, which gives us what is known as "standard time." However, as in New York City we are not quite as far west as the 75th meridian, we must obtain the actual time at the exact spot where we are located.

From the foregoing we know that when it is noon at Greenwich it is seven o'clock in the

morning by our standard time in New York; but to obtain our exact local time we must convert and apply our longitude in time. The longitude of the City Hall at New York is 74° 00′ 24″ west; at the rate of 15 degrees per hour this would equal 4h. 56m. 02s. Hence we have

Greenwich mean noon	12h. 00m. 00s.
N. Y. longitude in time, deduct...........	4h. 56m. 02s.
Local mean time in N. Y., A. M.........	7h. 03m. 58s.

So that when it is noon in Greenwich our clocks in New York would show 7 A. M., which is the mean time on the 75th meridian, whereas our exact local mean time would be 7h. 03m. 58s. A. M., and our clocks in New York City are therefore 3m. 58s. slow of actual local mean time. This may be proved as follows:

In New York our clocks are set on the

Time of longitude	75° 00′ 00″ W.
Actual longitude of City Hall	74° 00′ 24″ W.
Difference of longitude	59′ 36″

Now, applying the same rule of conversion, 15 degrees to the hour, we find that 59′ 36″ of

arc is equal to 3m. 58s. of time. For convenience in converting longitude into time, or vice-versa, use Table 7 of the Bowditch "Epitome."

Having found the exact local mean time, we must apply the equation of time to get the local apparent time, or time by the sun, which is irregular, changing from day to day, and is given in the nautical almanac for every day and hour in the year. For example, we have demonstrated above that at Greenwich mean noon, when our clock at New York City Hall shows seven A. M., the actual local mean time is 7h. 03m. 58s. Now the equation of time at Greenwich mean noon on, say, July 1, 1917, is 03m. 32s., and if we deduct this from our actual local time we have a local apparent time of 7h. 00m. 26s.

From the foregoing we find at the New York City Hall, on July 1, 1917:

Clock shows 75th meridian time...	7h. 00m. 00s. A. M.
Greenwich time	12 noon.
Local mean time	7h. 03m. 58s. A. M.
Local apparent time	7h. 00m. 26s. A. M.

All this by way of illustration; but as we do not find any ships floating around the New York City Hall, let us take a more practical example.

Every sea-going vessel carries one or more chronometers set on Greenwich time. Owing to slight, but ever present, mechanical imperfections, these chronometers gain or lose a little. This gain or loss is known as the "error," fast or slow, of the chronometer and a record is kept of it in the chart room.

Example

At sea, on May 16, 1917, an observation is taken for the purpose of finding the compass error, to compute which it is necessary to find the local apparent time, i. e., the apparent time at the ship the instant the observation is taken. By dead reckoning the ship's longitude is found to be 63° 45′ 30″ west, and the chronometer error is 2m. 18s. fast. What is the local apparent time at the instant of the observation?

Chronometer	7h. 48m. 12s. (P. M.)
Error (deduct)..................	02m. 18s.

Greenwich mean time	7h. 45m. 54s.
Longitude in time (deduct).....	4h. 15m. 02s.
Local mean time	3h. 30m. 52s.
Equation of time given by almanac for May 16th at 8 P. M., to be added to mean time.....	03m. 48s.
Apparent time at ship	3h. 34m. 40s. (P. M.)

From the foregoing, to find the local apparent time (L. A. T.), we evolve the following:

Rule

At the instant of the observation, take the Greenwich time by the chronometer and correct it for its error, fast or slow, which will be the Greenwich mean time (G. M. T.). Apply the longitude in time, adding it if the ship is east, and subtracting it if west of Greenwich; this gives the local mean time (L. M. T.). From the nautical almanac find the equation of time for the given day and hour. To the local mean time apply the equation, plus or minus, as shown by the almanac, and the result will be the local apparent time (L. A. T.).

CHAPTER III

COMPASS ERROR

The importance of a thorough knowledge of this subject cannot be overstated. There are two elements in compass error: variation and deviation. Variation is constant, i. e., it is always the same at any given point and is indicated on the chart. Off Sandy Hook it is 11 degrees (one point) westerly, and, going south, it diminishes until it disappears altogether in the Florida Straits. To find variation, look on the chart at the position of the ship, and take the nearest variation given.

Deviation is caused by local attraction, and varies according to surrounding conditions. Deviation will vary on the same ship. It changes on different courses because of the changing relative position of the needle and the object which causes its deflection. It may be almost eliminated by a professional compass adjuster,

who places small magnets around the binnacle, so located as to offset the local attractions on different courses. Even then, the adjuster always leaves a "deviation card" showing the residual deviation on each point.

Rule

To determine the total or net compass error proceed as follows: With an azimuth attachment, or pelorus, on the compass observe the azimuth, or direction, of the sun. Call this the "compass bearing." Take the time by chronometer and correct it for its "rate" (fast or slow). To this, apply the longitude of the place so as to get the local *mean* time. Then apply the equation of time (taken from the almanac for the given day), which will give the local apparent time. Now, with the latitude of the place to the nearest degree and the declination of the sun to the nearest degree and the apparent time, enter the azimuth tables and select the sun's true bearing. The difference between the compass bearing and the true bearing will be the error of the compass from the true north.

In north latitude the A. M. bearings are called north, so many degrees east; and P. M. bearings are called north, so many degrees west.

In south latitude A. M. bearings are called south, so many degrees east; and P. M. bearings are called south, so many degrees west.

Look from the center toward the outer circle of a compass card, and if the true bearing is to the right hand of the compass bearing, the error is easterly; if the true bearing is to the left of the compass bearing, the error is westerly.

If the compass has no deviation, the error thus determined will agree with the variation shown by the chart; but if the two do not agree, the difference will be the deviation, which will be ascertained as follows: If the error by azimuth is 6 degrees W. and variation by chart is 10 degrees E., the deviation is 16 degrees west.

If error by azimuth is 13 degrees W. and variation by chart is 5 degrees W., the deviation is 8 degrees west.

If error by azimuth is 18 degrees E. and variation by chart is 17 degrees E., the deviation is 1 degree east.

Examples

No. 1.	Latitude (to nearest degree)	38° N.
	Sun's declination for given day	5° N.
	Local apparent time	8h. 12m. A. M.
	Sun's bearing by compass	N. 100° E.
	True bearing as per azimuth tables	N. 107° E.
	Compass error	7° E.
	Variation given by chart	5° W.
	Leaving deviation	12° E.
No. 2.	Latitude	41° N.
	Sun's declination for given day	21° N.
	Local apparent time	4h. 10m. P. M.
	Sun's bearing by compass	N. 72° 45′ W.
	True bearing as per azimuth tables	N. 90° 51′ W.
	Compass error	18° 06′ W.
	Variation given by chart	11° W.
	Leaving deviation	7° 06′ W.
No. 3.	Latitude	41° N.
	Sun's declination for given day	21° N.
	Local apparent time	4h. 10m. P. M.
	Sun's bearing by compass	N. 101° 45′ W.
	True bearing as per azimuth tables	N. 90° 51′ W.
	Compass error	10° 54′ E.
	Variation given by chart	11° W.
	Leaving deviation	21° 54′ E.

No. 4.	Latitude	31° N.
	Declination	23° N.
	Local apparent time	7h. 40m. A. M.
	Sun's bearing by compass........	N. 93° 45′ E.
	True bearing as per azimuth tables	N. 80° 50′ E.
	Compass error	13° W.
	Variation	11° W.
	Leaving deviation	2° W.

No. 5.	Latitude	32° N.
	Sun's declination for given day...	23° N.
	Local apparent time	2h. 40m. P. M.
	Sun's bearing by compass........	N. 50° W.
	True bearing as per azimuth tables	N. 94° W.
	Compass error	44° W.
	Chart gives "no variation".......	00°
	Leaving deviation	44° W.

No. 6.	Latitude	48° N.
	Sun's declination for given day...	8° N.
	Local apparent time	6h. 30m. A. M.
	Sun's bearing by compass.........	N. 90° E.
	True bearing as per azimuth tables	N. 90° E.
	Apparent error (none)...........	00°
	Variation given by chart	5° W.
	Deviation	5° E.

The last example is a peculiar one. The chart shows a variation of 5 degrees west, so that with a true bearing of 90 degrees the compass should have shown 85°, but the local attraction has pulled the needle around to 90°, which shows an easterly deviation of 5°.

The student is earnestly urged to study with great care each of the foregoing examples in connection with the explanation and rule which precede them; and then, when opportunity offers, to practise taking azimuths, or bearings, of the sun with a pelorus, or other compass attachment, in order that he may thoroughly familiarize himself with that most important duty of finding compass error.

Care should be taken to avoid the common mistake of referring to all compass error as "variation of the compass" or "deviation of the compass." The two are entirely separate and distinct and should not be confused. The proper term is "compass error," which includes both variation and deviation.

Sturdy, in his excellent treatise on navigation, says:

The *compass* bearing of a heavenly body is taken,

and the *true* bearing for the same instant is calculated; the difference between the two must necessarily be the *error;* this is generally called "variation," *but it is not so,* because the effects of the iron in the vessel modify the bearing by compass. Hence every error computed on board ship is compounded of *variation proper and deviation,* and is the whole correction necessary to be applied to every bearing taken and course steered, etc.

There are other methods of obtaining compass error, as by amplitudes, lines of position, etc.; but the one given is the one most commonly used and will suffice.*

* A common method is "swinging ship" where light houses, buoys, etc., are available for taking bearings. *Deviation* may vary with change of cargo.

CHAPTER IV

DEAD RECKONING

HAVING mastered chart sailing, where the navigator is in sight of, or near land, and runs by observation of lighthouses, buoys, etc., we will now take the ship off shore, or "off soundings," and out of sight of land, where our position must be calculated by estimate predicated upon certain assumed facts, the accuracy of which depends largely upon careful study and experience. The methods thus employed in determining course and distance, and in fixing the ship's position, are commonly known as "dead reckoning."

The accuracy of this method of navigating depends upon two things: first, the accuracy of the compass and the skill of the quartermaster in steering correctly the courses as given; and secondly, the ability of the navigator to estimate accurately the distance run, which is ac-

complished either by the use of a taffrail log, or by counting and keeping a record of the revolutions of the engines, or by both. It may be stated theoretically that if the exact compass courses be maintained and the exact distances run be accurately computed, navigation by dead reckoning would be all-sufficient, and the use of sextant and chronometer to solve problems could be eliminated. The questions involved are simply problems in plane trigonometry and are easily solved by what are known as "traverse tables," found in Bowditch and other treatises on navigation. The student is now urged to make a careful study of the construction, meaning and practical use of these tables.

Traverse Tables

The three columns are headed respectively "DISTANCE," "LATITUDE," and "DEPARTURE." The degrees are found on the top of the page for 1 to 45 degrees, and at the bottom of the page for 45 to 90 degrees. Distance and latitude always mean the same, i. e., in latitude

one mile is always one minute and 60 minutes one degree.

Departure is really miles, and must not be mistaken for minutes of longitude, because while a degree of longitude on the equator is 60 miles, the degrees and minutes of longitude grow less as you go away from the equator toward the poles. A degree of latitude is always 60 miles, but a degree of longitude, for example, one-half way between the equator and the pole would be only about forty-five and one-third miles, and the minutes of longitude would be proportionately less than one mile. Now for the purpose of proportion or proper relation in triangulation, the traverse tables must necessarily be made with the same unit of length or distance in each of the three columns, and therefore, as above stated, departure must mean miles. Hence it becomes necessary, in certain calculations, to convert departure into minutes of longitude, and in other cases to convert minutes of longitude into departure.

There are two classes of problems which are constantly being worked out at sea by the traverse tables. In one of these there are given

the latitude and longitude from which the vessel starts, the distance she runs, and the degrees, or direction, of her course. In such a case, the problem is to find the latitude and longitude at the end of such a run. On the table of the degrees of the course, opposite the distance run, will be found the change of latitude and departure to be applied to the latitude and longitude left. To apply the latitude is simple; but, as departure is different from minutes of longitude, it must be converted into minutes before it can be applied to the longitude left. To do this, first find the degrees of middle latitude by adding together the latitude left and the latitude in, and dividing the sum by 2. Then, on the page of the degrees of the middle latitude, apply the departure in the latitude column, and to the left, in the distance column, will be found the number of minutes of longitude, which is applied to the "long. left," and the result is the longitude of the new position.

The second problem is one in which the latitude and longitude of the position left and the position sought are given, and the problem is to find the course and distance between these

two given points. For example, the ship gets her position, lat. and long., one day at noon, and again she gets her position at noon the next day. In this example the lat. and long. at both ends of the course are given, and the problem is to get the course and distance between the two points. Another problem of the same nature is to find the course and distance between two points, the lat. and long. of which are given on the chart. For example: find the course and distance from Cape Henry, Chesapeake Bay, to Nantucket Light Ship, which is on the route from Norfolk to Boston. In this problem we take the difference of the two latitudes and convert it into minutes. Next, get the degrees of middle latitude by adding together the two latitudes and dividing the sum by 2, as explained. Then get the difference of longitude and multiply the number of degrees by 60, adding the minutes. Now, as your difference of longitude is in minutes, which are less than miles, they cannot be applied in the traverse tables until the minutes of longitude have been converted into departure, or miles. To make this conversion, turn to the table of

the degrees of the middle latitude and apply the minutes of difference of longitude in the distance column, and to the right in the latitude column will be found the departure. Then search the pages of the traverse tables until you find the page where the change of latitude and the departure compare as nearly as possible, and to the left, in the distance column, will be found the number of nautical miles of the run. On this same page will be found the true course, reading from the top of the page if the latitude is greater than the departure, or from the bottom of the page if the departure is greater than the latitude.

In order that the student may keep clearly in mind the rules for converting departure into longitude, and vice-versa, the author recommends that the following memorandum be written on a flyleaf of the book of tables:

1. *To convert departure into longitude.*

   Apply departure in latitude column and distance column gives longitude.

2. *To convert longitude into departure.*

   Apply longitude in distance column and latitude column gives departure.

Middle Latitude Sailing

A ship takes her departure from a point between the Scotland and Ambrose Channel Light Ships in lat. 40° 28′ N., and long. 73° 50′ W. She sails a course of south 27° east 11½ hours at an average speed of 16½ knots per hour. Find her position, lat. and long., at the end of the 11½ hours.

Rule

Figure the total distance run. Turn to Table 2, Bowditch. On the page of the given course, in degrees, find the difference of latitude in the column opposite the number of miles run and apply it to the latitude left, adding it for a N. course, or substracting it for a S. course. The result gives the new latitude. Adding the new latitude to the latitude left and dividing the sum by 2 gives the middle latitude. From the same page find the departure in the second column opposite the distance column. Turn to the page of the degrees of middle latitude and apply the departure in the latitude column, and to the left, in the distance column, will be found the difference of longitude. Apply this

difference to the longitude left, adding it if the ship has made westerly, or subtracting it if the ship has made easterly, and the result will be the longitude of the ship at the end of the 11½ hours' run.

In applying this rule to the above and similar problems, the following form should be followed as closely as possible:

Lat. left	40° 28′ N.	Long. left	73° 50′ W.
11½ hours at 16½ knots = 190 miles on a 27° course = 169.3′, being.	2° 49′	Departure 86.3	
		Long. 111′ = ..	1° 51′
Latitude in ...	37° 39′	Long. in	71° 59′ W.
Lat. left	40° 28′		
Lat. in	37° 39′		
Divide by 2....	78° 07′		
Gives middle lat.	39°		

In the foregoing example, we first find the distance run, 189.75 miles. Then turning to Bowditch, Table 2, on the page headed with the course, 27°, and running down the distance

column to 190, we find the difference of latitude in the latitude column to be 169.3 minutes, or miles, which divided by 60 gives us the change of latitude of 2° 49′, which we set down under the latitude left; and as our course is southerly we deduct it, because, going south toward the equator, our latitude is growing less. At the same time that we take out our difference of latitude we find in the second column to the right, opposite the 169.3, the departure, 86.3. But this is the equivalent of miles, and must be converted into minutes of longitude before it can be applied to the longitude left. Following the rule, we next add the two latitudes and divide the sum by two, which gives the middle latitude, 39 degrees. Then in the same table, but on the page headed 39°, we look for the departure 86.3 in the latitude column, and to the left, in the distance column, we find 111, which is the difference of longitude in minutes, and which, divided by 60, gives 1° 51′, which we write down under our longitude left. As our course is easterly, toward Greenwich, our longitude is decreasing, and we therefore deduct it from the longitude left and

get 71° 59′ as the "longitude in" at the end of the run.

Another problem of a character very frequently met with at sea is stated hypothetically as follows:

Example in Dead Reckoning

A steamer in mid-ocean, bound W. Her position is definitely determined by observation at noon on Wednesday as being in lat. 47° 18′ N. and long. 38° 32′ W. Immediately after the noon observation on Wednesday she runs into a fog, which continues two days or more. On the following Friday she passes, at 4.45 A. M., close to a dangerous derelict, the location of which it is her duty to report. Her course has been south, 78° west, and her average speed 9½ knots per hour. What was the position of the derelict?

If not a derelict it might be an iceberg, or possibly a sailing vessel flying the signal "report me to my owners."

Following would be the solution, worked out the same as the preceding problem, excepting that in this case, as the ship is making consid-

erable westerly, an allowance of 45 minutes is made in the time of the run for the difference of longitude, as will be seen in the following:

SOLUTION

Lat. left	47° 18′ N.	Long. left	38° 32′ W.
Wednesday noon to Friday 4.45 A. M., 40¾ hours plus 45 M. diff. long. equals 41½ hours at 9½ m. = 394 m. at S. 78° W. = 81.9 (—)	1° 22′	Dep. 385.4 = 565 m. =...	9° 25′
Lat. in	45° 56′	Long. in.......	47° 57′ W.
" left	47° 18′		
÷ 2..........	93° 14′		
Middle lat.....	47°		

Position of derelict
Latitude 45° 56′ N.
Longitude 47° 57′ W.

A third problem, and a very common one, is to find the position of a vessel at noon of a given day by finding the course and distance from the known position of the preceding day, no observation having been available. In this case,

the course being westerly, the time from noon to noon is 24 hours and 15 minutes.

By observation a ship's position at noon is found to be

Lat. 35° 27′ N.
Long. 53° 42′ W.

She runs into a fog, and up to noon the following day she runs 24 hours and 15 minutes at an average speed of 11½ knots per hour on a course of N. 72° W. Find her position by dead reckoning at noon of the following day, no observation having been obtainable.

SOLUTION

Lat. left	35° 27′ N.	Long. left	53° 42′ W.
24¼ hours at 11½ knots = 278 miles at N. 72° W. = 86′ = (+)	1° 26′	Departure = 264.4 Long. 330′ = (+) .	5° 30′
Lat. in	36° 53′ N.	Long. in	59° 12′ W.
Lat. left	35° 27′		
Divide by 2....	72° 20′		
Gives middle lat.	36° 10′		

Hence position at noon of second day by dead reckoning is

Latitude	36° 53′ N.
Longitude	59° 12′ W.

Course and Distance

The foregoing examples solve the problem of finding the position of a ship at the end of a run when the position of departure, the course and distance are given. The other problem for which the traverse tables are used is to find the course and distance between two positions, the latitude and longitude of both being known. For example: given the latitude and longitude of two successive days, what is the "course and distance" between the two positions? Or, taking departure from a lightship or buoy, and computing the course and distance to another lightship or buoy, where the exact position of both departure and destination are known. This problem is solved either by "middle latitude" or by "Mercator sailing." The two methods are nearly alike in results, but the middle latitude method is preferable where the course is nearly east or west. Otherwise, use

Mercator. Middle latitude is worked by Table 2 and Mercator by Table 3, Bowditch.

Let us take first a middle latitude example.

Problem No. 1

By observation, a ship's position at noon is found to be

Lat. 42° 45′ N.
Long. 65° 22′ W.

At noon of the following day her position, as determined by observation, is

Lat. 45° 50′ N.
Long. 56° 38′ W.

What has been her course and how many miles has she made from noon to noon?

Middle Latitude Rule

Find the difference of degrees of latitude and longitude. Convert degrees of both into minutes. Find the middle latitude by adding the two latitudes and dividing by 2. On page of the degrees of middle latitude, Table 2, ap-

ply the difference of longitude in the distance column, and to the right, in the latitude column, will be found the departure.

In Table 2, turn to the page where difference of latitude and departure compare, or match, as nearly as possible, and in the distance column, to the left, will be found the number of miles sailed. The true course will be found at the top of the page if the latitude is greater than the departure, or at the bottom of the page if the departure is greater than the latitude.

SOLUTION

Lat. left	42° 45′ N.	Long. left	65° 22′ W.
Lat. next day..	45° 50′ N.	Long. next day	56° 38′ W.
Diffce. lat.....	3° 05′	Diffce. long. ...	8° 44′
= 185′		= 524′ or,	
Lat. in	42° 45′	Departure	376.9
Lat. next day..	45° 50′		
Divide by 2....	88° 35′	Distance	420 miles
Gives middle lat.	44° 17′	True course....	N. 64° E.

In this case we find that the difference of latitude, 185′, is the equivalent of miles; where-

as the difference of longitude, 524′, is minutes which, as before explained, are not miles or departure. The two quantities, therefore, cannot be compared in the traverse tables until we have converted the minutes of longitude into miles, or departure. Hence, following the rule, we turn to Table 2, with the degrees of the middle latitude, 44, and by applying the longitude 524 in the distance column, to the right, in the latitude column, we find 376.9, which is the departure. Now we have the two quantities of the same character, miles, and we then look through Table 2 and find the page where the latitude and departure compare as nearly as possible; reading from the top of the page if the difference of latitude is greater than the departure, or from the bottom of the page if the departure exceeds the latitude. In this case we find on page 583, Bowditch, reading from the bottom of the page, 377.5 in departure column, and 184.1 in latitude column, while to the left in distance column, we find 420 miles, which is the distance run. At the bottom of the page we find the angle of the true course to be 64, and as our latitude has been increasing and our

longitude decreasing, we name the course N. 64 E.

Problem No. 2

From San Juan, Porto Rico, to New York. The departure from San Juan harbor is in lat. 18° 29′ N., and long. 66° 08′ W. The destination, between the Ambrose Channel and Scotland Light Ships off Sandy Hook, is in lat. 40° 29′ N., and long. 73° 55′ W. Find the course and distance.

Solution

Lat. left	18° 29′ N.	Long. left	66° 08′ W.
Lat. sought ...	40° 29′ N.	Long. sought ..	73° 55′ W.
Diffce. lat.	22° 00′	Diffce. long. ...	7° 47′
= 1320′		= 467′, or	
Lat. in	18° 29′	Departure	408.4
Lat. sought ...	40° 29′		
Divided by 2..	58° 58′	Distance	1,380 miles
Gives middle lat.	29° 29′	Course	N. 17° W.

In this case, the latitude being greater than the departure, the course is found and the head-

ings of the columns read from the top of the page. As the latitude, 1320, is too large a quantity to be found in the tables, we divide both quantities by 10 and seek for comparison 132.0 and 40.8. On page 564 we find the closest comparison to be 40.3 in the departure column and 132.0 in latitude column. To the left, in the distance column, we find 138. Now as the other two quantities have been divided by 10 we must multiply the distance by 10 to preserve the proper relation. This gives us 1380 as the distance, and the course at the top of the page as 17°. As we are increasing both latitude and longitude the course must be named N. 17° W.

Problem No. 3

From New York to Bermuda. The point of departure for the regular Bermuda steamers from New York is between the Scotland and Ambrose Channel Light Ships in lat. 40° 29′ N. and long. 73° 55′ W. The point of destination, located just far enough north to clear the reefs at Bermuda, is in lat. 32° 28′ N. and long. 64° 35′ W. Find the true course and distance.

Solution

Lat. left	40° 29′ N.	Long. left	73° 55′ W.
Lat. sought ...	32° 28′ N.	Long. sought . .	64° 35′ W.
Diffce. lat.	8° 01′	Diffce. long. ...	9° 20′
= 481′		= 560′, or	
Lat. in	40° 29′	Departure	453.1′
Lat. sought ..	32° 28′		
Divided by 2..	72° 57′	Distance	660 miles
Gives middle lat.	36° 28′	Course	S. 43° E.

In this case we seek a page of the tables where we can compare lat. 48.1 with dep. 45.3, and on page 616 we find 48.3 in lat. column and 45.0 in dep. column. In the distance column to the left we find 66, which multiplied by 10, as we have divided the other quantities by 10, gives the distance, 660 miles.

On the run to Bermuda it is an interesting problem to compute what allowance should be made for the Gulf Stream. As the course of the ship is practically S. E. and the drift of the stream N. E., the ship crosses the stream at right angles. Assuming the stream to be 190 miles wide and the speed of the ship 15¾ knots

per hour, the ship would be in the stream, say, 12 hours. Now if the velocity of the stream is 1¼ knots per hour, the N. E. drift of the ship during the 12 hours of crossing would be 15 miles. Therefore the point to be steered for should be 15 miles to the S. W. of the true destination, i. e., opposite to the direction of the current. Hence

True destination lat.	32° 28′ N.	Long. . . .	64° 35′ W.
15 miles S.W. (minus) . .	11′	(plus) . .	12′
Destination for compass.	32° 17′ N.		64° 47′ W.

Now by the traverse tables we find that from the given departure to this corrected destination the course would be S. 42 E., or only one degree to the southward of the first determined course.

Having become familiar with middle latitude sailing, the student should now acquire a thorough understanding of

Courses and Distance by Mercator

Find the difference of latitude and the difference of longitude and convert into min-

utes, the same as in middle latitude sailing. From Table 3, Bowditch, select the meridional parts of the latitude in and the latitude sought, and if the two latitudes are of the same name, N. or S., subtract one from the other; if of different names, one N. and the other S., add them together. The result will be the "meridional difference of latitude."

Make meridional difference of latitude and difference of longitude compare in Table 2 by seeking meridional difference of latitude in latitude column, and difference of longitude in departure column. On same page the course will be given at top of page if meridional difference of latitude is greater than difference of longitude, but at the bottom of the page if difference of longitude is greater than meridional difference of latitude. Apply *real* difference of latitude in latitude column, reading from that part of page where the course was found, and to the left, in the distance column, will be found the distance in miles.

EXAMPLE

Lat. left	42° 45′ N.	Long. left	65° 22′ W.
Lat. next day..	45° 50′ N.	Long. next day.	56° 38′ W.
Diffce. lat.	3° 05′	Diffce. long. ...	8° 44′
= 185′		= 524′	

Meridional parts of lat. left..................	2826.7
Meridional parts of lat. next day.............	3084.4
Meridional difference of lat.	257.7

Course, N. 64° E.
Distance, 422 miles.

After finding the meridional difference of latitude, 257.7, and the difference of longitude, 524, we see that their nearest comparison, reading from the bottom of the page, is on page 583, Bowditch tables, and at the bottom of that page we find that the course is given as 64°. As the ship is increasing its latitude and decreasing its longitude, we name the course N. 64° E.

But the distance is not taken from the point opposite where the two quantities compare. The object of finding *this* page of comparison is merely to get the angle or course. Following the rule we apply the real difference of

latitude, 185, in the latitude column, reading from the bottom of the page as the course is found there, and opposite, to the left in the distance column, is found the distance, 422 miles.

By way of further comparison, let us apply the Mercator method to problem No. 2 on page 36.

Example

Lat. left	18° 29′ N.	Long. left	66° 08′ W.
Lat. sought ...	40° 29′ N.	Long. sought ..	73° 55′ W.
Diffce. lat.	22° 00′	Diffce. long. ...	7° 47′
= 1,320′		= 467′	

Meridional parts of lat. left..................	1121.3
Meridional parts of lat. sought...............	2645.5
Meridional difference lat.	1524.2

Course, N. 17° W.
Distance, 1,380 miles

In this case it will be observed that the result is the same as by the middle latitude method.

Finally, to work out problem No. 3, New York to Bermuda, on page 37, we have the following:

EXAMPLE

Lat. left	40° 29′ N.	Long. left.	73° 55′ W.
Lat. sought ...	32° 28′ N.	Long. sought ..	64° 35′ W.
Diffce. lat.	8° 01′	Diffce. long. ...	9° 20′
= 481′		= 560′	

Meridional parts of lat. left..................	2645.5
Meridional parts of lat. sought................	2048.9
	596.6

Distance, 660 miles
Course, S. 43° E.

In this last case we find the nearest comparison in Bowditch, page 616, where, in lat. and dep. columns, reading from top of page:

Actual, as above	59.6	56.
Nearest in table	59.2	55.2
Or	60.0	55.9

In this case again, we have to divide the quantities by 10, as before explained; and as we cannot find the true latitude, 481, we divide it also by 10, and finding 48.3 the nearest figure in the lat. column, we take 66 from the distance column and multiply it by 10 to get the distance of 660 miles.

CHAPTER V

SOUNDINGS

BEFORE leaving the subject of dead reckoning, this would seem to be an appropriate place to interpolate a word on the use of the lead and line. Many a shipwreck has been attributable to gross, criminal negligence of the use of this most important aid to navigation. A conspicuous example was the steamer *St. Paul* some twenty-five years ago. Racing to the westward with her deadly rival, the *Campania*, thick weather nearly all the way across the Atlantic, a three-days' northeast gale retarding the N. E. drift of the Gulf Stream, no observations for several days, both ships found themselves about ten miles south of their course, and the *St. Paul* ran upon the Jersey beach. The author crossed on the return trip of the *Campania*, and Captain Walker, alluding to the incident, remarked: "I didn't know where I was, but 15 fathoms

was good enough for me, and I let go my mud-hook and went to bed; the next morning the fog lifted, and there was the *St. Paul* with her nose up among the cottages on the Jersey beach.'' Returning on the *Campania*, in about 47° west longitude, icebergs one day were seen about ten miles to the N. W., and the temperature of the water had taken a sudden drop. Running on the Banks a thick fog was encountered, and aside from the usual precautions of closing the watertight compartments, doubling the number of lookouts, etc., the lead was kept going, although it seemed we had at least one thousand fathoms under us; but among experienced and cautious navigators, the invariable rule, ''Never assume anything,'' seems to prevail, and it is a most excellent rule to follow. The approach to New York Harbor is probably one of the easiest in the world. With the Jersey beach running north and south and the Long Island beach running east and west, both having the soundings and changing character of the bottom plainly noted on the chart, approaching the harbor from the sea is like running into a great funnel. If the lead is prop-

erly used there is absolutely no excuse for running aground.

The ordinary hand lead, weighing about 10 or 12 pounds, is attached to a stout line on which are the following marks of measurement:

2 fathoms..........	2 leather strips
3 fathoms..........	3 leather strips
5 fathoms..........	1 white rag
7 fathoms..........	1 red rag
10 fathoms..........	1 leather with hole in it
13 fathoms..........	Same as 3
15 fathoms..........	Same as 5
17 fathoms..........	Same as 7
20 fathoms..........	Two knots

For deeper soundings the line is marked with an extra knot for every ten fathoms. The larger leads have a hole in the lower end filled with tallow which brings up specimens of the bottom for comparison with the chart.

The larger transatlantic sea-going vessels, and some of the coasters, use the Sir William Thompson sounding apparatus by which great depths may be ascertained while running at full speed.

Off Shore Work

Now the student will be taken off soundings, out of sight of land, and introduced to the use of the sextant for the solution of problems in elemental nautical astronomy.

The sextant is an instrument designed for the sole purpose of determining angular measurements; either vertically, as with the angular height of the sun or other heavenly body from the horizon, or horizontally, to ascertain the angular distance between any two objects. A description of its construction and directions for its use are not necessary in this brief treatise. This information may be obtained from any good work on navigation such as Bowditch, "Epitome," Chapter VIII, and also in "The Navigator's Pocket Book," by Captain Howard Patterson. The student is urged to consult one of these works, and then to adopt the more practical plan of taking altitudes with someone who is familiar with the use of the sextant.

Before proceeding with an explanation of any of the problems, the solution of which is

derived from what is called "observed altitude," we must first consider, and thoroughly understand, what is known as corrected altitude.

CHAPTER VI

CORRECTED ALTITUDE

After ascertaining an altitude by the use of a sextant there are four corrections to be made in order to get the "true central altitude" as follows:

Semi-Diameter.—The difference between the center and the lower periphery of the sun. Found in the nautical almanac for every day in the year. Semi-diameter is always to be added, when lower periphery is observed.

Dip.—An allowance made for the height of the observer's eye above the surface of the water, and is always to be deducted. It is found in Table 14, Bowditch.

Parallax.—The difference between the center of the earth and its surface; it is always to be added. It is found in Table 16, Bowditch.

Refraction.—The divergence of the rays of the sun in passing through the atmosphere of

the earth. (Like the apparent bending of a stick in a pail of water.) Refraction varies from nothing at the zenith, to about 36 minutes at sunrise or sunset. It is always to be subtracted. It is found in Bowditch, Table 20.

The foregoing four corrections are always to be made in observations of the sun or moon. Some sextants have an error called "Index Error." In such cases, if the error is on the arc it is to be subtracted; if it is off the arc it is to be added. A very good rule for correcting the index error on a sextant is the following:

On the arc is off—or minus.
Off the arc is on—or plus.

EXAMPLE

An observation from the bridge of a ship at sea, on May 5, 1917.

Height of bridge from surface of the water is 42 feet, to which should be added, say, 5 feet for the height of the observer's eye above the floor of the bridge.

Altitude of the sun as observed with a sextant (known as "observed altitude"), is 23° 42′ 15″. Index error on the arc is 02′ 40″.

Problem, to find the "T. C. A.," or true central altitude.

Observed altitude	23° 42′ 15″
Index error, on the arc, minus..............	02′ 40″
	23° 39′ 35″
Semi-diameter, plus	15′ 89″
	23° 56′ 04″
Dip, minus	06′ 36″
	23° 49′ 28″
Parallax, plus	08″
	23° 49′ 36″
Refraction, minus	02′ 11″
True central altitude	23° 47′ 25″

For convenience of reference, write the following on a flyleaf in Bowditch:

Altitude Corrections

Semi-diameter, Almanac	....	Plus
Dip	Table 14, Bowditch.........	Minus
Parallax	Table 16, Bowditch.........	Plus
Refraction	Table 20, Bowditch.........	Minus

Sextant Index Error

On the arc is off—or minus

Off the arc is on—or plus

With the 1914 edition of Bowditch, Table 46, the altitude correction may be found by inspection, thereby using only one correction instead of four, as in the foregoing example. The student, however, should familiarize himself with the application of the four corrections as the usual method of computing the true central altitude.

Now that we understand how to correct our observed altitude and find the T. C. A., we are ready to consider latitude.

CHAPTER VII

LATITUDE

BETWEEN the extended plane of the equator and the "elevated" (or extended) pole is an angle of 90 degrees. Hence north latitude begins to count from zero at the equator, to 90 degrees at the north pole. Halfway between the equator and the north pole would be latitude 45 degrees N. When the sun is over the equator, its altitude, measured by a sextant, if deducted from 90 degrees, will give the latitude of the observer. For example: if the sun is over the equator and the observer is on the equator, the observed altitude of the sun is 90 degrees, which deducted from 90 degrees, leaves nothing, or no latitude. As the observer moves north the altitude of the sun diminishes. If the altitude should be 70 degrees, the latitude would be 20 degrees, 90—70=20. If the observer should go so far north as to find an alti-

tude of only 30 degrees, he would be in latitude 60 degrees N., as 90—30=60. If, however, the sun is not directly over the equator, the declination north or south must be applied in order to get the true latitude. Suppose the sun has a north declination of 10 degrees and that the observed altitude is 60 degrees; deducting the 60 from 90 degrees we get 30, but that is not the correct latitude because the sun is already north of the equator. The 30 degrees is called "zenith distance," and to this we must add the 10 degrees of the sun's north declination in order to get the true latitude which is 40 degrees N. Thus—

Angular distance equator to pole...	90 degrees
Deduct observed altitude..........	60 degrees S.
Gives zenith distance	30 degrees N.
Add North declination of sun.....	10 degrees N.
Gives true latitude	40 degrees N.

Hence we have the following:

Rule

At noon, when the sun is on the merid, or at its maximum altitude, bearing due N. or S.,

measure the altitude with a sextant and observe the approximate Greenwich time. Correct this altitude for semi-diameter, parallax, dip and refraction (see rule for corrected altitude) which will give the "true central altitude." Deducting this "T. C. A." from 90 degrees will give the "zenith distance," which is named the opposite of the sun's bearing (N. or S.).

From the nautical almanac find the sun's declination for Greenwich noon of the given day. In the adjoining column will be found the "hourly difference" of declination (called "H. D"). This shows the amount of change in declination each hour from Greenwich noon. Multiply this H. D. by the number of hours from Greenwich noon. Apply this correction to the declination given for Greenwich noon and the result will be the "corrected declination" or the exact declination at the time of sight. This correction will be plus or minus, according to the following rule:

If declination increasing, A. M. minus
If declination increasing, P. M. plus
If declination decreasing, A. M. plus
If declination decreasing, P. M. minus

Now apply this "corrected declination" to the "zenith distance," adding it if of the same name; but if one is north and the other south, deduct the lesser from the greater and the result is the latitude which takes the name of the larger quantity, N. or S.

Example

At sea, June 2, 1917.
Greenwich chronometer, 4.15 P. M.
Height of eye, 40 feet.

Observed alt.	71° 48′ 16″ S.		
Semi-diameter	15′ 48″		
	72° 04′ 04″	Declination, noon	22° 09′ 09″ N.
Parallax ...	04″	Correction +	01′ 25″
	72° 04′ 08″		
Dip	06′ 12″		22° 10′ 34″
	71° 57′ 56″		
Refraction...	31″	Hourly diffce.	20″
T. C. A.....	71° 57′ 25″ S.	Multiplied by hours from noon......	4¼
Applied to..	90°		
Zenith dist..	18° 02′ 35″ N.		85″
Declination..	22° 10′ 34″ N.	Being	01′ 25″
Latitude ...	40° 13′ 09″ N.		

In computing declination it must always be corrected to the time of sight. In the above example the almanac gives the declination on June 2nd as 22° 09′ 09″. But that is for Greenwich noon. The almanac also gives the hourly difference, or the amount of change for each hour, as 20″. Now as the Greenwich chronometer at the time of our sight showed 4:15 P. M., the correction would be 4¼ hours at 20″ per hour, or 85″, being 1′ 25″, which must be applied to the declination at noon in order to get the declination at the time of sight. As the almanac shows us that the declination is increasing, and as the time of our sight was after Greenwich noon, this must be added to the noon declination.

In ascertaining the declination for the time of sight, there are four different ways of applying the correction or "hourly difference."

First. In the foregoing example it is obvious that as the declination is increasing, and the time of sight is after Greenwich noon, the correction must be added, or plus.

Second. With the declination increasing, and the time of sight before Greenwich noon, the

declination at sight is less than at noon and the correction must therefore be subtracted, or minus.

Third. If the declination is decreasing, and the time of sight is after Greenwich noon, the declination at sight is less than at Greenwich noon, and the correction must therefore be subtracted, or minus.

Fourth. If the declination is decreasing and the time of sight is before Greenwich noon, the declination at sight is more than at Greenwich noon, and the correction must therefore be added, or plus.

If the student will carefully study the foregoing explanation so as to understand the reasons, he will never be at a loss to know how to apply the correction; but for convenience of reference, and to avoid possible error, he might write the following condensed rule in the back of his Bowditch:

Declination increasing, P. M. plus,
Declination increasing, A. M. minus,
Declination decreasing, P. M. minus,
Declination decreasing, A. M. plus.

If the new Government Almanac for 1917 is

used, the correction for hourly difference is eliminated as the sun's declination is given for Greenwich noon, and at intervals of two hours thereafter.

In the example given on page 56 the Greenwich time of the sight is 4:15 P. M. By turning to page 16 of the government almanac we find that the declination is 22° 10.4′ at four o'clock P. M. The difference for 15 minutes of time, in this case, would be only five seconds of arc, which is negligible. Four-tenths of one minute of arc is equal to 24 seconds; so that the declination given by the government almanac for June 2nd at 4:00 P. M. is 22° 10′ 24″, the same as that computed by the hourly difference in the example on page 56.

The following chapter gives a condensed rule for ascertaining latitude by a meridian altitude of the sun.

CHAPTER VIII

LATITUDE BY SUN ON MERIDIAN

SHORT RULE

CORRECT the altitude for semi-diameter, dip, parallax and refraction, and note the Greenwich time.

Deducting this "T. C. A." from 90 degrees gives "Zenith Distance," to be named the opposite from bearing of the sun N. or S.

To the sun's declination for Greenwich noon, apply the "hourly difference" (multiplied by number of hours from Greenwich noon), which gives declination at time of sight.

Apply this corrected declination to the zenith distance, adding it if it be of the same name, N. or S., but if of different names deduct the lesser from the greater and the result is the latitude, which takes the name of the larger quantity, N. or S.

NOTE.—Do not forget: Always name bearing N. or S. of observed altitude, zenith distance and declination, in order to determine whether latitude is N. or S.

Example No. 1

At sea, in west longitude, May 7, 1917. Greenwich chronometer, 4h. 30m. P. M. Height of eye, 40 feet.

Observed alt.	52° 43′ 30″ S.	Declination for Greenwich noon	16° 43′ 56″ N.
Index error, off (+) ..	02′ 00″	Correction (+)	03′ 09″
	52° 45′ 30″		16° 47′ 05″ N.
Semi-diameter (+)	15′ 52″		
	53° 01′ 22″	Hourly diff.	42″
Parallax (+)	05″	Multiplied by number of hours from Greenwich noon	4½
	53° 01′ 27″		189″
Dip (—) ..	06′ 10″	Being	3′ 09″
	52° 55′ 17″		
Refraction (—).	44″		
True central alt.	52° 54′ 33″ S.		
Subtracted from	90° 00′ 00″		
Gives zenith distance .	37° 05′ 27″ N.		
Declination (+)	16° 47′ 05″ N.		
Latitude ...	53° 52′ 32″ N.		

From the above it will be seen that the observation must have been made in west longitude

because the Greenwich time was later than noon at the ship.

EXAMPLE No. 2

At sea, November 13, 1917. Greenwich chronometer, 9h. 46m. A. M. Height of eye, 40 ft.

Observed alt.	38° 22′ 15″ S.
Index error, off (+)..	02′ 00″
	38° 24′ 15″
Semi-diameter (+)	16′ 12″
	38° 40′ 27″
Parallax (+)	08″
	38° 40′ 35″
Dip (—)...	06′ 12″
	38° 34′ 23″
Refraction (—).	01′ 13″
T. C. A...	38° 33′ 10″
Subtracted from	90° 00′ 00″
Gives zenith distance .	51° 26′ 50″ N.
Declination (—).	17° 52′ 15″ S.
Latitude ...	33° 34′ 35″ N.

Declination for Greenwich noon	17° 53′ 45″ S.
Correction (—)	01′ 30″
	17° 52′ 15″ S.

In the foregoing example the ship must have been in east longitude because the Greenwich chronometer was earlier than noon at the ship. As the declination was increasing, it must have been less at 9:46 A. M. than at noon; the correction, therefore, must be subtracted.

Now let us work out an example in which the ship's latitude was between the sun's declination and the equator. In this case the declination will be taken from the government almanac, and the altitude will be corrected by Bowditch, Table 46.

EXAMPLE No. 3

At sea, in west longitude, June 5, 1917. Greenwich chronometer, four o'clock P. M. Height of eye, 46 feet.

Observed alt.	79° 51′ 00″ N.
Correction table 46 (+)	09′ 12″
T. C. A.	80° 00′ 12″ N.
Subtracted from	90° 00′ 00″
Gives zenith distance	9° 59′ 48″ S.
Declination	22° 32′ 12″ N.
Latitude	12° 32′ 24″ N.

Note that as the observer is only 12° 32′ 24″

north of the equator, and the sun's declination is 22° 32′ 12″ north, the observer must face the north to observe the sun's altitude, and the observed altitude is therefore named 79° 51′ north. Then following the rule, when we deduct the corrected altitude from 90° to get the zenith distance, the latter must be named opposite to the altitude, or south. Now, applying the north declination to get the latitude, if the two differ, N. and S., as they do in this case, we deduct the lesser from the greater, and the result, which is the latitude, takes its name from the greater, or north.

From the foregoing the student will recognize the absolute necessity of applying correctly the signs N. and S., in working out all latitude sights.

It is a common practice at sea for the captain and navigating officers to assemble on the bridge at about fifteen minutes before apparent noon, and begin to take altitudes of the sun with their sextants. Altitudes are measured and read in quick succession and comparisons are made between the assembled officers until the highest altitude is reached. The order for eight

bells is given,* and the latitude is then computed, compared, and agreed upon.

There are times at sea when the sun is obscured by clouds at the exact time of its meridian passage (apparent noon). By the use of the new Bowditch tables (26 and 27) it is possible to ascertain the latitude by an observation taken at any time between 26 minutes before and 26 minutes after apparent noon. This is known as an "ex-meridian" sight. Its accuracy depends upon the accuracy of the ship's longitude by dead reckoning for the purpose of determining the exact *local* apparent time. If the sun is out any time after 26 minutes before apparent noon and there is a prospect of its being obscured at noon it is advisable to take an ex-meridian as a precautionary measure.

* The Navy method is somewhat different. The latitude is first calculated and reported to the Captain who then orders 8 bells.

CHAPTER IX

LONGITUDE

LONGITUDE is time. The circumference of the globe is 360 degrees, which, divided by 24, the number of hours in a day, gives 15 degrees as the change of longitude each hour. Longitude begins at Greenwich and counts to the westward halfway around the earth to 180°, and eastward to halfway around in the opposite direction to 180°. The difference between Greenwich time and New York standard time is five hours; which, at 15 degrees per hour, gives us a longitude of 75° west. On our California coast the difference between Greenwich time and the standard time used there is 8 hours; which, at 15 degrees per hour would be 120°. Mare Island Navy Yard, San Francisco, for example, is in 122° 16′ 24″ west longitude, or about 2° to the westward of the longitude from which they take their standard time.

Going to the eastward from Greenwich, the difference of time between Greenwich and the observatory at Petrograd, Russia, for example, is 2h. 01m. 17s., which, at 15 degrees per hour, puts Petrograd in 30° 19′ 22″ east longitude. Going still further east to the Chinese coast we would find that the difference in time between Greenwich and Shanghai, for example, is 8h. 05m. 56s., which, at 15 degrees per hour, puts Shanghai in 121° 29′ 00″ east longitude.

From these simple but practical examples the student will now understand that if we are able at any time to compute the local time at any given point on the globe, and at the same time ascertain the Greenwich time, the difference in time will give us the longitude, east or west. This explains why a ship always carries a chronometer set at Greenwich time.

The following is a simple illustration of the principle governing the method employed to ascertain, by measuring the altitude of the sun, the local time at the ship. Suppose that the ship is on the equator and the sun is directly over the equator, or "on the line," which occurs only in March and September. Now, if

the sun is directly overhead, 90°, we know that it is 12 o'clock noon. If the sun is directly underneath it must be 12 o'clock midnight. When the sun is on the eastern horizon it must be halfway between midnight and noon, or 6 o'clock A. M. If, by a sextant, we find its altitude to be 45° above the horizon, or halfway between the horizon and the zenith position at noon, the time would be halfway between the time of 6 A. M. and noon, or 9 A. M. Likewise, if the sun is on the western horizon halfway between noon and midnight we know the time would be 6 P. M. If, by a sextant, we find the altitude of the sun in the west to be 45° above the horizon or halfway between the horizon and the zenith, we know the time would be halfway between noon and 6 P. M., that is, 3 P. M. In other words, from the altitude measured by the sextant we get what is known as the "hour angle" of the sun, which is the time at the spot where the observation was made.

But the ship is not on the equator and the sun is not over the equator and therefore the latitude of the ship, the sun's declination, and the sun's altitude, constitute the "Argument"

of a problem in spherical trigonometry which is readily solved by the use of logarithms.

To compute the longitude by a chronometer sight of the sun, study carefully the following:

Rule

Observe an altitude and at the same time note the time by the Greenwich chronometer. Apply the four corrections (page 51) to the observed altitude and get the "true central altitude."

Ascertain "polar distance" (which is the angular distance between the sun and pole nearest the observer) by deducting the corrected declination of the sun from 90 degrees if the sun is in the same hemisphere as the observer; or by adding the declination if the sun is on the opposite side of the equator. For example: if in the northern hemisphere the sun has a north declination of 10 degrees the polar distance would be 80 degrees. In the same hemisphere if the sun is 15 degrees south declination the polar distance would be 105 degrees.

Determine the latitude of the ship at the time of sight, either by dead reckoning or otherwise.

Add together the degrees, minutes and seconds of the corrected altitude, the polar distance, and the latitude by dead reckoning respectively, and divide the sum by 2, which gives the "one-half sum." From the one-half sum deduct the true central altitude, which gives what is called the "remainder." From Table 44, Bowditch, select logarithms as follows:

Secant of the latitude,
Cosecant of the polar distance,
Cosine of the one-half sum,
Sine of the remainder.

Add the four logs thus obtained and divide that sum by 2, which gives the log. "sine" of time. This will be found under the "sine" column in Table 44; opposite, to the left, will be found the local "apparent time" at the ship at the time of observation.

"Apparent time" is irregular. "Mean time" is clock or chronometer time and is regular. To convert "apparent time" into "mean time," apply what is known as the "equation of time," found in the nautical almanac, for Greenwich noon each day of the year, adding

or subtracting it, as stated at the head of the almanac column, and the result will give "mean time" at ship. The difference between "mean time" at ship and the "mean time" at Greenwich, as shown by the chronometer, will be the longitude in time.

Turn to Table 7, Bowditch, and converting the time into Arc will give the longitude, which will be named east or west, in accordance with the following well-known rule:

> Greenwich time best, longitude west;
> Greenwich time least, longitude east.

The following observation was made by the author with an artificial horizon at Greenwich, Connecticut, and is selected because of its absolute accuracy, the exact latitude and longitude of the spot being definitely known. This was an A.M. sight, June 28, 1917. The altitude obtained with an artificial horizon is double the actual altitude, and therefore must be divided by 2.

The following abbreviations are used:

Art. hor. ....Artificial Horizon
Alt. corr. ....Altitude correction
I. E. ....Index error

T. C. A. ....True central altitude
Lat. ....Latitude
P. D. ....Polar distance
½ S. ....One-half sum
Rem. ....Remainder
L. A. T. ....Local apparent time
L. M. T. ....Local mean time
G. M. T. ....Greenwich mean time
Equa. ....Equation of time

EXAMPLE NO. 1

Artificial Horizon, A.M., Sight, July 28, 1917

Art. Hor......	107° 20′		
÷2.......	53° 40′ 00″		
Alt. Corr. (+)	15′ 07″		
T. C. A.......	53° 55′ 07″		
Lat..........	41° 00′ 45″	sec.	.12232
P. D.........	70° 57′ 24″	cosec.	.02444
÷ 2........	165° 53′ 16″		
= ½ s.....	82° 56′ 38″	cosin.	9.08938
T. C. A. (−)..	53° 55′ 07″		
Rem.........	29° 01′ 31″	sin.	9.68592
			18.92206
÷ 2.............			9.46103

From A.M. column	9h. 45m. 36s.
Corr. (−).........	02s.
L. A. T...........	9h. 45m. 34s.
Equa. (+)........	06m. 19s.
L. M. T..........	9h. 51m. 53s.
G. M. T..........	2h. 46m. 22s.
Long. in time.....	4h. 54m. 29s.
Longitude.......	73° 37′ 15″W

Chron.......	2h. 47m. 44s. P.M.
Fast.........	01m. 22s.
M. T. G.....	2n. 46m. 22s. P.M.
Dec'l........	19° 02′ 36″.
	90° 00′ 00″
P. D.........	70° 57′ 24″

This is the exact longitude shown by the chart at the spot where the observation was made, proving that the "error" given for the chronometer was correct.

The latitude was accurately taken from the chart. To obtain the polar distance, the declination at the time of sight, 19° 02′ 36″, was taken from the government almanac and *deducted* from 90°, because the sun is *north* of the equator. (See rule.)

After adding the four logs. and dividing the sum by 2, we get the log. sine of time, 9.46103. Turning to Bowditch, Table 44, on page 788, running down the sine column, we find the nearest preceding log. to be 9.46095, opposite which, to the left in the A. M. column, is given 9h. 45m. 36s. But we want 9.46103, or 8 *more* than the log. we have taken. In a small separate table at the bottom of the same page we find opposite column A the figure 11, which is the nearest to our difference of 8; and above 11 we find 2 seconds, which is the correction to be applied to the time given for log. 9.46103. Running down the column, we find that as the log. increases, the time decreases; hence the cor-

rection of 2 sec. must be deducted in order to get the exact time for the log. we want. Now, having found the local apparent time, we apply the equation of time, according to the almanac, which gives us the local *mean* time. Deducting the L. M. T. from the G. M. T., we find the difference in time to be 5h. 54m. 29s. To convert time into arc, use Bowditch, Table 7, or the following simple rule:

1 h. = 15°, so multiply the hours by 15.
4 m. = 1°, so divide the minutes by 4.
4 s. = 1′, so divide the seconds by 4.

Thus:

4 h. × 15 =	60° 00′ 00″	
54 m. ÷ 4 =	13° 30′ 00″	
29 s. ÷ 4 =	07′ 15″	
Longitude	73° 37′ 15″	west.

Applying the rule, we find that Greenwich time is "best," and therefore the longitude is west.

The 1914 edition of Bowditch has a new table called "Haversines" (Table 45), which shortens the method used in Example No. 1,

eliminates the "correction" for the log. sine, and so reduces the chance of error. In the preceding problem, which is given as an example only because it is the method most commonly used, adding the four logs. and dividing by 2 gives the "log. sine of time." In the new method, the addition of the four logs. is called "Haversine," and the time is taken by inspection without correction. Applying this new method to Example 1 we have the following: Sum of the 4 logs. = Haversine 18.92206. Table 45 gives P.M. time at the top of the page and astronomical time at the bottom of the page, from which latter 12 hours must be deducted to get the "civil" A.M. time. Hours and minutes are given at the head and foot of the column under the caption "Log. Hav.," and seconds for P. M. sights in the extreme left-hand, and for A.M. sights in the extreme right-hand column. Turning to page 837, we find the nearest log. hav. to be 8.92210, omitting the index. The time being A.M., we get from the foot of this column 21h. 45m., or 9h. 45m. A.M. In the extreme right-hand column, opposite the selected log., we find 34 sec., which gives the time

of 9h. 45m. 34s. A.M., the same time as the L. A. T. found by the former method, but without the necessity of any correction.

The old almanacs give the equation of time for Greenwich noon, and in the adjoining column the "hourly differences," with which to correct the equation for the time of sight. In the new government almanac the equation is given for Greenwich noon and for intervals of two hours thereafter, so that no correction is necessary, the equation at time of sight being taken out by inspection. But the new almanac gives the sign, plus or minus, to be applied to Greenwich *mean* time; so that instead of converting local apparent time into local mean time, as in Example No. 1, we convert the Greenwich mean to Greenwich apparent time by applying the equation to the G. M. T.

In the following examples the Haversine method will be used and the equation of time will be applied as explained above. Seconds of arc are omitted, which is the common practice at sea. In Example No. 2 the ship is nearing the Greenwich meridian, but is still in west longitude, off the south coast of Ireland. In Exam-

ple No. 3 the ship is in east longitude, in the Mediterranean Sea.

EXAMPLE No. 2

Nov. 12, 1917. Height of Eye, 26 ft.

Ob. alt.........	24° 39′			Chron..........	10h. 27m. 09s. A.M.
I. E., off......	10			Slow...........	01m. 14s.
	24° 49′			M. T. G........	10h. 28m. 23s.
Alt. Corr. (+)	09′			Equa. (+)......	15m. 50s.
T. C. A.......	24° 58′			A. T. G.........	10h. 44m. 13s. A.M.
Lat. D. R.....	51° 25′	sec.	.20506		
P. D..........	107° 37′	cosec.	.02086	Dec'l Nov. 11...	17° 37′ S.
					90°
+ 2........	184° 00′			P. D...........	107° 37′
½s.........	92° 00′	costn.	8.54282		
T. C. A. (−)..	24° 58′				
Rem.........	67° 02′	sin.	9.96413		
Log. Haversine..........			18.73287		

A. T. at ship .... 10h. 12m. 27s. A. M.
A. T. at Greenwich .... 10h. 44m. 13s. A. M.

Longitude in time .... 31m. 46s.

31 m. = ... 7° 45′ 00″
46 s. = ... 11′ 30″

Longitude .... 7° 56′ 30″ W.

In the above example, as Greenwich time is best, longitude is west. The government almanac gives the declination for each day begin-

ning at noon; therefore we take the declination for the preceding day, November 11, or 22h. 28m. astronomical time, which is the same as 10h. 28m. A.M., November 12, civil time.

Example No. 3

At sea, July 4, 1917.
A. M. Sight.
Height of eye, 45 feet.
Greenwich chronometer, 6h. 58m. 59s. A. M.
Chron. error, 1m. 42s. fast.
Latitude by dead reckoning, 37° 36′ N.

Ob. alt.......	27° 40′	
I. E., off......	06′	
	27° 46′	
Alt. Corr. (+)	08′	
T. C. A......	27° 54′	
Lat. D. R.....	37° 36′ sec.	.10112
P. D.........	67° 04′ cosec.	.03576
÷ 2........	132° 34′	
½ s........	66° 17′ cosin.	9.60446
T. C. A. (−)..	27° 54′	
Rem.........	38° 23′ sin.	9.79304

Chron...........	6h. 58m. 59s. A.M.
Fast..............	01m. 42s.
G. M. T.........	6h. 57m. 17s. A.M.
Equa. (−).......	04m. 03s.
G. A. T..........	6h. 53m. 14s.
Dec'l......	22° 56′ N.
	90° 00′
P. D......	67° 04′

Log. Haversine....	19.53438
L. A. T. (at ship)..	7h. 13m. 33s. A.M.
A. T. Greenwich...	6h. 53m. 14s. A.M.
Longitude in time..	20m. 19s.
20m. =..........	5° 00′
19s. =..........	04′ 45″
Longitude.....	5° 04′ 45″ East

In this case, as the Greenwich time is least, the longitude must be east. By reference to the chart we find the ship's position in the Mediterranean Sea.

In taking out the declination, as the government almanac gives astronomical time which begins at noon, the time of this sight being July 4th at 7 A.M., the astronomical time would be July 3rd at 19 o'clock. Turning to the almanac we find, page 18, the declination to be

July 3d, 18 o'clock.......... 22° 56.3′ N.
July 3d, 20 o'clock.......... 22° 55.8′ N.

Therefore, 19 o'clock being halfway between, we call the declination, omitting seconds of arc, 22° 56′ N. Now, as we are in N. latitude and the declination is N., it must be deducted from 90° to get the polar distance, 67° 04′.

The same rule applies to the equation of time. On the same page of the almanac we find the equation to be

July 3d, 18 o'clock............ 4m. 02.6s.
July 3d, 20 o'clock............ 4m. 03.5s.

Therefore, at 19 o'clock July 3rd, or 7 A.M. July 4th, the equation would be 4 m. 03 sec.

For practice, the student is recommended to work out each of the foregoing examples separately, by taking the data given, viz., the height of eye, chronometer and rate, and the latitude by dead reckoning, and from this data work out the examples without this book; if the result is incorrect, the error may be found by comparison with the detailed figures herein given.

In giving these examples it has been assumed that the student understands the use of logarithms. If not, reference is made to Captain Patterson's "Pocket Book," page 85.

When the student thoroughly understands working out a chronometer sight of the sun, it will be a very easy matter for him to do what is known as chronometer rating.

CHAPTER X

LATITUDE BY SUN, EX-MERIDIAN

SIGHT must be taken within limits of the Bowditch table, either 26 minutes before or 26 minutes after 12 o'clock noon, apparent time. Take G. M. T. by chronometer at instant of sight and reduce it to G. A. T. by applying equation. Apply longitude in time which will give local A. T., showing the number of minutes from local apparent noon.

Table 26, with latitude and declination to nearest degree, get amount of correction for 1 minute from noon.

Table 27, with number of minutes from Greenwich noon, get correction to be applied to altitude by taking out for even number and then for decimal fraction. Add the two which gives the correction.

Correct the observed to the T. C. A. and add the correction as above. With this corrected

altitude find the latitude in the usual manner. But, as this is the latitude at time of sight, figure the distance run (for so many minutes before or after noon) and apply that difference to get the latitude at apparent noon.

Ex-Meridian Example

At sea, December 20, 1917

Chron., G. M. T.	4h. 56m. 49s. P. M.
Equation (plus)	02m. 03s.
G. A. T.	4h. 58m. 52s. P. M.
Longitude, 72° 42′ W..............	4h. 50m. 46s.
Time from apparent noon	8m. 06s.

Bowditch, Table 26, for latitude 37 N. and declination 23 S., gives 1.7″ for each minute of difference from noon. Table 27 gives, under column of 8 minutes:

Differ. for 1″	1′ 04″
Differ. for .7″	45″
Total correction (say 2′)	1′ 49″

Observed altitude	29° 02′ S.
Correction (plus)	08′
T. C. A.....................................	29° 10′
Bowditch corr. for 8 m. from noon (as above)	02′
	29° 12′ S.
	90°
Zenith distance	60° 48′ N.
Corr. declination	23° 27′ S.
Lat. at time of sight	37° 21′ N.
Add 8m. at 12 knots..................	02′
Lat. at noon	37° 23′ N.

CHAPTER XI

CHRONOMETER RATING

To "rate" a chronometer means to find its error, fast or slow. This is determined when the exactly correct longitude of the ship is known. On a moving ship this may be ascertained from the chart, either by cross bearings, by four-point bearings, or by steering the ship close to a buoy the exact longitude of which is shown on the chart. At the exact instant that the true longitude is thus ascertained, take a chronometer sight of the sun for longitude and work it out. If the longitude given by this chronometer sight of the sun is the same as the longitude shown by the chart at the instant the sight was taken, then there is no error in the chronometer. But if the longitude found by the sight differs from the true longitude as given by the chart, then the difference between these two longitudes, if converted from arc into

time, will give the "error" of the chronometer, fast or slow. Or, convert each of the two longitudes into time, and the difference of these times will give the error of the chronometer, fast or slow.

If the longitude of the observation is *west* of the true longitude, the chronometer is *fast*. If the longitude by observation is *east* of the true longitude, the chronometer is slow.

EXAMPLE No. 1

Longitude by observation,	83° 19′ 15″ W.	5h. 33m. 17s.
Longitude by chart,	83° 02′ 30″ W.	5h. 32m. 10s.
Chronometer error		1m. 07s.

Or

Longitude by observation,	83° 19′ 15″
Longitude by chart (true),	83° 02′ 30″
	16′ 45″

which equals 1m. 07s. fast.

EXAMPLE No. 2

Longitude by chart (true) 76° 13′ 00″ W.	5h. 04m. 52s.
Longitude by observation, 72° 42′ 00″ W.	4h. 50m. 48s.
	14m. 04s. slow.

Or

Longitude by chart (true),	76° 13′ 00″ W.
Longitude by observation,	72° 42′ 00″ W.
	3° 31′ 00″ W.

which equals 14m. 04s. slow.

NOTE.—A chronometer may be accurately rated on shore with the use of an artificial horizon, provided the exact longitude of the place is definitely ascertainable.

CHAPTER XII

STARS AND PLANETS

It is the belief of the author that a thorough knowledge of the contents of this brief treatise up to this point is sufficient to enable a man to navigate a vessel to any part of the world. Therefore, the student is urged first to thoroughly master all that precedes this chapter, leaving that which follows to be studied at sea. If the student has become familiar with the rules for working out a chronometer sight of the sun, he can easily acquire by himself a knowledge of the stars and planets sufficient to enable him to determine latitude or longitude by either a star or planet if he will carefully study and follow the rules hereinafter given. Without going into an elaborate or technical astronomical dissertation, a brief explanation will suffice.

Right ascension and sidereal time are the ele-

ments used with the stars and planets in working out chronometer sights for longitude. Right ascension may be defined as the celestial longitude of a heavenly body expressed in hours, minutes and seconds. It is reckoned eastward on the equinoctial from the First Point of Aries, which is that point in the heavens directly over the equator, which the sun crosses from south to north on the 21st day of March.

Sidereal time, or time by the stars, is the period between the passage of a star over a given meridian, and its next succeeding passage, which is 23h. 56m. 04s., and which constitutes what is known as a sidereal day, which is 3m. 56s. shorter than the mean solar day.

Right ascension of the meridian is the hour angle between the meridian of the observer and the meridian of the First Point of Aries, is reckoned eastward, and is the same thing as sidereal time.

To ascertain time by an observation of a star or planet we proceed exactly the same as with the sun (except as to corrected altitude) until we have added our logs. and from them have taken out the time, or hour angle, which is

sidereal time; this must therefore be converted into mean solar time before it can be applied to the Greenwich time to get the longitude.

We have learned that to find the true altitude of the sun we must apply to the observed altitude the four corrections of semi-diameter, dip, parallax, and refraction. With the stars, we apply only two corrections, dip and refraction; these are computed and applied exactly the same as with the sun. The other two corrections are eliminated for reasons that will be obvious. Semi-diameter would be negligible even if it were possible to measure it. Parallax is the angular difference when a heavenly body is viewed from two different points, i. e., from the surface or the center of the earth, separated approximately 4,000 miles. It is obvious that the nearer the observed body is to the earth, the greater will be the allowance for parallax. The body nearest the earth is the moon, at a distance of, say, 235,000 miles. The allowance for the parallax of the moon is therefore very important, as it ranges from 54 to 61 minutes, or miles. With the sun at a distance of over 92,000,000 miles, the maximum allowance for

parallax is only nine seconds of arc, or about one-seventh of a mile, which is practically negligible.

The distance of the stars, however, is so great that whether viewed from the center or surface of the earth the angular difference is negligible even if it were possible to compute it. Take, for example, Arcturus, a star commonly used by navigators; its distance from the sun is the incomprehensible figure of 2,546,229,254,400 miles! Or, expressed more intelligibly, more than 2,500 billions.

With these brief preliminary explanations, we may now consider the method of finding:

Longitude by a Star

Observe an altitude, note the chronometer and correct the altitude for dip and refraction (no semi-diameter or parallax). With this corrected altitude, the latitude and the star's polar distance (nautical almanac for declination), proceed exactly the same as with a chronometer sight of the sun as far as the log. sine of time, which is always applied in the P. M. column (Bowditch, Table 44). Or the Haversine meth-

od, Table 45, may be used. To the time thus obtained apply the star's right ascension (nautical almanac), adding the two if the star is west of the meridian; or, if the star is east of the meridian, deducting the former from the latter,* and the result will give the "right ascension of the meridian." From this (adding 24 hours if necessary) deduct the *mean* right ascension of the sun (nautical almanac, page 2, correcting from Greenwich noon to time of sight), and the result will give the mean astronomical time at ship, which, applied to the Greenwich astronomical time, will give the longitude in time.

Astronomical Time

The astronomical day begins at noon (12 hours preceding the civil day), and counts 1 to 24 hours (noon to noon). For example:

Civil Day	*Astronomical Day*
June 15, 11: P.M.	June 15, 11: o'clock
June 16, 1: A.M.	June 15, 13: o'clock
June 16, 4: A.M.	June 15, 16: o'clock
June 16, 9: A.M.	June 15, 21: o'clock
June 16, 11: A.M.	June 15, 23: o'clock
June 16, 1: P.M.	June 16, 1: o'clock

In astronomical time (1 to 24) there is no A. M. or P. M.

* Adding 24 hours if necessary.

Examples

In longitude 75 W., civil date June 15th, 9: P. M. English chronometer would show 2: A. M. of June 16th. Astronomical time would be June 15th, 14 o'clock.

In the same longitude, local civil time at ship, June 15th, 4: A. M., chronometer would show June 15th, 9: A. M., which would mean astronomical time, June 14th, 21 o'clock.

Hence, declination, right ascension, etc., for Greenwich noon must be taken from the almanac for the astronomical date and the corrections for "hourly difference" computed and applied accordingly.

The author has a scrapbook full of star sights which he has taken at sea, but as they are worked out with the old almanac, he has taken an observation of Arcturus, with an artificial horizon, at his summer home on Long Island Sound, and worked it out by the new government almanac so as to present to the student an example worked out by the latest methods. As heretofore explained, the altitude observed with an artificial horizon must be divided by 2 in

order to get the actual altitude from the real horizon; no allowance has been made for dip nor height of eye; otherwise the following example is worked out exactly the same as if at sea.

The exact location of the spot where the observation was taken is lat. 41° 00′ 45″ N. and long. 73° 37′ 15″ W. The seconds of arc are used for the purpose of greater accuracy. This was a P.M. sight made on July 19, 1917, and Arcturus, the star observed, was west of the meridian. The result was exactly correct, to the second of arc, proving the accuracy of the observation and the correctness of the chronometer error.

Looking down the left-hand side of the following example, the polar distance was found by taking the declination from page 95 of the nautical almanac. The nearest Haversine log., 9.33918, is found in Bowditch, Table 45, on page 855, and the time given for P. M., at the top of page, is 3h. 42m.; opposite the log. in the left-hand column we find 52 seconds.

The right ascension of the star is found on page 94 of the government almanac under the

EXAMPLE

Art. Hor......	76° 46′		
+ 2.......	38° 23′		
Ref'r.........	01′ 14″		
T. C. A.......	38° 21′ 46″		
Lat..........	41° 00′ 45″	sec.	.12230
P. D.........	70° 23′ 18″	cosec.	.02596
+ 2.......	149° 45′ 49″		
½ s.......	74° 52′ 55″	cosin.	9.41633
T. C. A. (−)..	38° 21′ 46″		
Rem.	36° 31′ 09″	sin.	9.77459
Haversine............			19.33918
Time from P.M. column			3h. 42m. 52s.
Star's Rt. Ascen. (+)..			14h. 11m. 55s.
Rt. Ascen. Merid......			17h 54m. 47s.
Sun's Rt. Ascen.......			7h. 49m. 18s.
Local astronomical M. T.			10h. 05m. 29s.
Greenwich astronomical M. T.			14h. 59m. 58s.
Longitude in time......			4h. 54m. 29s.

4h. = 60°
54m. = 13° 30′
29s. = 07′ 15″

Longitude... 73° 37′ 15″ west

Chron.......	15h. 00m. 55s.
Fast.........	57s.
M. T. G.....	14h. 59m. 58s.
Decl.........	19° 36′ 42″
	90°
P. D.........	70° 23′ 18″
Sun's Rt. Ascen.	7h.46m.50.2s.
Corr. (+)....	02m. 27.8s.
	7h.49m.18s.

constellation name of "a Bootis," which stands in line with the "special" name of Arcturus on page 95.

According to the rule, the right ascension is to be added because the star is west of the meridian. This gives us the right ascension of

the meridian from which we always subtract the sun's right ascension corrected to the time of sight, which gives us the local astronomical mean time. As the new almanac gives the *mean* right ascension of the mean sun, we do not have to apply the equation of time as we would have to do if we were given the *apparent* time of the sun's right ascension.

Turning to the right-hand side of the example we find "Chronometer 15h. 00m. 55s." Of course the chronometer actually read 3h. 00m. 55s., but that meant A. M. of civil time of the following day, or July 20th, to which we add 12 hours; the result being 15h. 00m. 55s. astronomical time of July 19th.

It should be noted that with a star there is no correction for hourly difference of declination or right ascension.

The sun's right ascension is found on pages 2 and 3 of the government almanac. On page 3 the right ascension for Greenwich noon for July 19th is given as 7h. 46m. 50.2s.; but this observation was taken 14h. 59m. 57s. after Greenwich noon; hence we must add the correction for, say, 15h. from the table at the bottom

of page 3, which gives the R. A. at the time of sight taken.

Longitude by a Planet

This problem is worked out exactly the same as by a star, except that the right ascension and declination must be corrected for the Greenwich time of the sight. The government almanac gives the right ascension, declination, etc., of four of the planets: Venus, Mars, Jupiter, and Saturn, on pages 78 to 93. The corrections are found by taking the small figures interpolated on the right of each column and applying them in almanac, Table IV, of Proportional Parts, on page 116. In the declination column the plus sign means north, and the minus sign south, declination. With this exception the example given on page 93 for working out a star sight will apply to a planet.

Longitude by the Moon

The moon is rarely used for any practical work at sea; principally because the rapidity of

its movement and the uncertainty of its periphery, or form, make it very difficult to get an accurate altitude. Yet, by using great care, the author has frequently taken an altitude of the moon in the east and a star in the west, or vice-versa, and worked out both sights within a mile or so of each other. The method of working out a chronometer sight of the moon is similar to that of a planet with the following exceptions: All four corrections for semi-diameter, parallax, dip, and refraction, must be applied to the observed altitude in order to obtain the T. C. A. The data for the moon for two-hour intervals will be found in the nautical almanac for every day in the year on pages 30 to 75. At the headings of the columns we find the G. M. T., meaning Greenwich mean time; S. D., meaning semi-diameter, and H. P., meaning horizontal parallax. After applying semi-diameter and dip in the usual manner, we take the horizontal parallax and turn to Table 24, Bowditch, pages 694 to 701, and, by inspection, take out one correction for parallax and refraction combined. This correction must always be

added because the moon's parallax is greater than the refraction.

Latitude by Star or Planet

The method of computing latitude by an observation of a star or planet on the meridian is exactly the same as that given for the sun on page 61 except that the observed altitude is corrected only for dip and refraction, no allowance being made for semi-diameter or parallax.

Latitude by Polaris may be found at any time of the night when the horizon is clear, by following the rule given in the government almanac in Table 1, page 111.

There is another method, somewhat shorter and simpler, which is more commonly in use at sea. Following is the rule:

Latitude by Polaris

Observe an altitude and correct the same for dip and refraction. At the instant of the observation, note the Greenwich time by the chronometer, which reduce to Greenwich astronomical mean time (G. A. M. T.). Find the sun's mean right ascension for Greenwich mean noon.

From Table 9 of Bowditch, or Table III, nautical almanac, find the correction for the time from Greenwich noon. Add these three quantities together, and if their sum exceeds 24 hours, deduct 24 hours, and the result will be the right ascension of the meridian at Greenwich or Greenwich sidereal time. Now find the longitude of the ship as accurately as possible, and converting it into time (Bowditch, Table 7), apply it to the Greenwich sidereal time, adding it if in east longitude or deducting it if west, and the result will be the local sidereal time, or R. A. M. at ship. With this local sidereal time enter table on page 111 of the nautical almanac and take out the correction, which is to be added to or subtracted from the T. C. A., according to the sign given in the table (— or +). The result will be the latitude of the ship at time of sight.

Example

At sea, March 21st, 1917. Observed altitude of Polaris 42° 25′. Longitude 61° 40′ W. Height of eye, 40 ft. Chronometer, 9h. 46m. 24s. A. M. (being 21h. 46m. 24s. of astronom-

ical time Mch. 20th). Chron. rate 1m. 45s. slow. Find the latitude.

Obs. alt. ....42° 25′ 00″	Chronometer ... 9h. 46m. 24s.
Corr. (—).. 07′ 21″	Rate, slow .... 01m. 45s.
T. C. A.....42° 17′ 39″	M. T. G........ 9h. 48m. 09s.
Corr. Alm. T. I. 33′ 24″	Add ....12h.
Latitude ...42° 51′ 03″	G. A. M. T. 20th. 21h. 48m. 09s.
	Sun's R. A. G. noon 20th....23h. 49m. 47s.
	Corr. Table III, Naut. Alm.... 03m. 35s.
	45h. 41m. 31s.
	Deduct ....24h.
	G. Sid. T......21h. 41m. 31s.
	Longitude (W.) in time ...... 4h. 06m. 40s.
	Local Sid. T....17h. 34m. 51s.

The latitude must be north, as Polaris cannot be seen south of the equator.

Observations of stars and planets are very useful and should be constantly practiced. The difficulty is to get a good, sharp horizon at night. The best time for such observations is shortly before sunrise, or shortly after sunset. In the morning, before the stars disappear, there

is generally sufficient light of dawn to get a good horizon; and in the evening, after the sun has set, when the more brilliant stars first appear, the horizon remains visible in the twilight.

Now having explained the most important methods of navigation in use at sea, the author recommends to the student the study of the following books, the first two of which are of course indispensable:

"AMERICAN PRACTICAL NAVIGATOR," originally by Nathaniel Bowditch, LL.D., reëdited and published by the U. S. Hydrographic Office, the latest edition of which was in 1914. If the student does not desire the full "Epitome" he may get the Tables published separately in a smaller volume. These may be obtained by applying to the Hydrographic Office in Washington, or from Bliss, or Negus, or other dealers in nautical books and instruments.

"THE AMERICAN NAUTICAL ALMANAC," usually referred to as the "government" or "nautical" almanac, is published each year by the Nautical Almanac Office, U. S. Naval Observatory, and is printed and sold by the Government Printing Office, Washington, D. C. It

may also be purchased of any of the dealers in nautical instruments for the nominal price of fifty cents.

"THE NAVIGATOR'S POCKET BOOK," by the late Captain Howard Patterson, with whom the author studied for many years, is not an epitome or treatise, but more in the nature of a dictionary or reference book, alphabetically arranged, and is a most helpful book for the student of navigation, no matter how far advanced he may be. A new and revised edition has just been published by Charles Scribner and Sons, New York.

"ELEMENTS OF NAVIGATION," by W. J. Henderson, A. M., Lieutenant in the First Naval Battalion of New York, recently revised and published by Harper and Brothers, New York. This book is not only thorough and comprehensive, but elementary and rapidly progressive as well. For clarity and conciseness of its explanations it is unexcelled. Mr. Henderson's well-known ability and long years of experience as a writer have been utilized to great advantage in his clever elucidation of the many compli-

cated and perplexing problems in the study of navigation.

In the effort to simplify these problems, and present them to the beginner in a condensed form and in a manner that may readily be understood by anyone to whom the subject is entirely new, the author has entertained the hope that when the student has thoroughly mastered the contents of this little book he may continue his studies with the admirable work of the author's friend and colleague, W. J. Henderson, recently revised and enlarged (May, 1918).

CHAPTER XIII

GENERAL REMARKS

ATTENTION has already been directed to the importance of knowing one's ship; but repetition is allowable by way of emphasis. The two most essential things for the navigator to be able to determine with the greatest possible accuracy are courses and distance, the former pertaining to the compass and the latter depending upon the means of estimating accurately the rate of speed.

To be able accurately to keep run of one's course the compass error must be determined at frequent intervals. Even if the ship's run is confined to an area where the variation is practically constant, the deviation nearly always changes on different courses and, for unknown reasons, frequently changes on one course. Hence the absolute necessity of taking frequent azimuths and computing the error. On the big

liners this is required to be done on every watch. If the navigator is too busily occupied with other duties the junior officers should be taught and required to do this most important work. In many cases two compasses are used: one, called the steering compass, is placed in front of the quartermaster and is generally more or less deflected by the iron in the steering gear. The other, called the standard compass, should be placed where it is least affected by local attraction. The selection of the position of the standard compass should be made as the result of careful experiment. With two compasses the courses are set by the standard compass and communicated to the quartermaster or officer of the watch by a whistle or other signal. But, even with a standard compass, vigilance in frequent taking of azimuths and computing the error must never be relaxed.

In dead reckoning, distance run as computed from the rate of speed may be determined in two different ways, viz., by the taffrail log, or by counting the revolutions of the engines. In either case due allowance must be made for current, which is generally indicated by the chart.

The necessity for making this allowance is obvious. Wherever there is a current the distance traveled through the water is never the same as the distance traveled over the bottom or past the land.

The taffrail log may be fairly accurate, but its error, plus or minus, must be determined by constant comparison with actual distance run, whenever the latter can be accurately known. A careful record of this error should always be kept. Care should also be taken to keep the log free from accumulating seaweed or other débris.

The engine room record, particularly in the larger vessels, affords an accurate means of estimating distance run. The engineer should know (or if not, he should learn) the proper percentage of slip to apply, at different rates of speed. From careful and constant experiment the navigator ought soon to know how many revolutions to count per mile and also to compute the hourly rate of speed from the number of revolutions per minute. Whenever the vessel is running along the coast, in sight of land or between buoys and lighthouses, the navigator, knowing

accurately the exact distance run, should always compare it with the taffrail log and with the engine room record. This will afford a reliable means of computing the error in either or both the two methods.

One of the most fertile sources of accident at sea is error due to the personal equation. Common mistakes in simple addition are perhaps among the most frequent. It is therefore a rule aboard all well-regulated vessels that every calculation of importance shall be checked or verified by an under officer. In ascertaining latitude the captain is supposed to summon all the navigating officers on the bridge for the noon observation and results are compared.

For longitude, either two men work at the same time or observations are so frequent that any error would be discovered by the next succeeding observation.

A notable example of the importance of this rule is the loss of a large transatlantic liner some years ago. The captain, a well-known and experienced navigator, added 90 and 16 and made it 126 instead of 106. Thus he overran his course 20 miles, or rather tried to, but a

reef of rocks stopped him, and the ship was wrecked because of his mistake in addition, which even his cabin boy could have discovered.

Some years ago the S. S. *Mohegan,* bound from London to New York, got her position off the Eddystone light, as usual, from which her course should have been west by south to clear the Lizard. She ran on the manacles, considerably to the northward of her course and some three hundred lives were lost. At the official inquiry the quartermaster, who was at the wheel when she struck, swore that the course given him when off the Eddystone was west by north. The officer of the watch was drowned, so that there was no one to contradict or confirm the quartermaster; but there is no doubt that the officer did inadvertently give the course as west by north, and this *lapsus linguæ* caused the loss of about three hundred lives.

Since then there has been an almost universal rule requiring the course to be put up before the quartermaster in black and white after it has been computed by the captain and verified by an officer, so that there can be no chance of a misunderstanding of oral orders.

Always when on soundings keep your lead going and study the depths and character of the bottom in comparison with the chart.

When proceeding parallel to a coast take frequent "four-point bearings," which will not only give you your exact distance from the coast but also an accurate point of departure from which to lay out your next course.

It has been well said that "eternal vigilance is the price of victory." Lieutenant Henderson very aptly puts it, "Eternal vigilance is the price of safety at sea." This maxim should be burned deep into the soul of every navigator.